Development of Gamma-Ray Compton Imager Using Room-Temperature 3-D Position Sensitive Semiconductor Detectors - Phase II

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During the second year period of this NEER project, our group at the University of Michigan has focused on the construction of compact Compton imagers using the results obtained during the first year, especially those results from the optimization of detector configurations and Monte-Carlo simulations of gamma-ray interactions with the detector materials. The challenges and complexities of constructing the first Compton-scattering gamma-ray imagers using wide band-gap semiconductors are significant. Parallel detector assembly efforts have been carried out using two suppliers in order to guarantee our tasks will be accomplished during the period of this project. In addition, we have been developing the VAS-TAT multi-channel readout system to replace the VA1 system employed in the first generation 3-dimensional position sensitive CdZnTe detectors. Compared to the previous VA1 system, the new VAS-TAT chip pairs provide some unique functions previously unavailable. This includes (1) the measurement of electron drift times in addition to the energy depositions, even for multiple-scattering gamma-ray events, (2) the employment of peak-hold circuitry on each of 32 independent channels to eliminate the error caused by varying peaking times of different channels, and (3) the availability of a self-trigger that will significantly reduce the low energy threshold from ~100 keV to not more than a few tens of keV. All these functions are critical for detection efficiency and angular resolution of a Compton-scattering gamma-ray imaging device. In order to overcome the problems with the first generation VAS-TAT system developed by IDE AS (a Norwegian company) produced in the Phase I period, the required modifications have been identified and the second generation VAS-TAT system has been under development since February of this year. Our ongoing work and accomplishments during this reporting period are detailed below.

1. **Objective:** Construct two 3-dimensional position sensitive CdTe detectors using the plate-through-via technique in collaboration with Acrorad in Japan.

   Accomplishments: Based on our Monte-Carlo simulation results using the EGS-4 program, (which models the interactions between gamma-ray and detector material, the ionization process of the charged particle, and the transport and diffusion of charges within the device.) it was determined that a dimension of ~1×1 mm on each anode pixel is optimal for detecting gamma-rays in the energy range of 10 keV to 1 MeV (the optimization was targeted for the range of 500 - 600 keV which has important applications in medical imaging, nuclear spectroscopy and astrophysics). In addition, from our previous measurement results on the first CdTe detector, which has a dimension of 20×20×15 mm and an array of 11×11 anode pixel (each pixel is ~ 1.7×1.7 mm square), the configuration of the two CdTe detectors for the Compton-scattering imager was determined. Each detector has a dimension of 12.5×12.5×10 mm with 11×11 anode pixels fabricated on the anode surface. An important change to the previous CdTe detector is the removal of a common non-collecting anode grid between anode pixels. It was observed that the leakage current between each anode pixel and the common grid was too high for the multi-channel VAS-TAT chips. However, the elimination of the grid between anode pixels makes the diagnosing of the detector more difficult since tests between each pixel and its eight neighboring pixels must be performed. Using the earlier design, tests were required only between the anode pixel and the common grid. Fifteen plate-through-via ceramic plates were fabricated at Acrorad. Eight of those plates were used at their Okinawa plant for detector assembly, and rest of the plates were delivered to our group for the future development of pixellated semiconductor detectors at the University of Michigan. The construction of both detectors is completed. The first CdTe detector for our Compton-scattering imager was received on June 8th and is being tested. The second detector is being tested at Acrorad and should be delivered to us this month.

2. **Objective:** Construct two 3-dimensional position sensitive CdZnTe detectors using plate-through-via technique in collaboration with eV Products in the United States**.**

   Accomplishments: Two 3-dimensional position sensitive CdZnTe detectors are being constructed at eV Products. Since the bulk resistivity of CdZnTe is about 10 times higher than that of CdTe, CdZnTe detectors can offer better signal to noise ratio. However, this is the first attempt to construct 3-dimensional CdZnTe detectors using the plate-through-via technique. Significant efforts have been spent in the design of anode electrodes and in the investigation of fabrication process. The key difference from the CdTe anode electrode is a common non-collecting anode grid surrounding all anode pixels. This enhances the small pixel effect and simplifies the diagnostic process during detector assembly. After the detectors are fabricated, the surface resistivity and noise at a typical bias voltage will be measured between each anode and the common grid. The delivery of two 3-D CdZnTe detectors is scheduled for the August-September period.

3. **Objective:** Upgrading the first generation VAS-TAT data acquisition system in collaboration with IDEAS in Norway.

   Accomplishments: The first generation VAS-TAT data acquisition system for 3-D pixel detectors was delivered in the summer of 1999. The system was tested extensively until the end of 1999. Although the main functions worked as planned, significant modifications were required. This included the dynamical range of the TAT chip, the uniformity of the independent channels and the trigger mode of the special channel (#1) on each chip. The specifications for the second-generation system were proposed to IDE AS in January 2000. The new system will upgrade the hybrid-repeater boards (which interface, handle data communication and provide power to the VAS-TAT chip pairs), and the VAS-TAT chips. The first few second-generation hybrid-repeater boards should be delivered by the end of June 2000. The new hybrid-repeater cards will be mounted with the first generation VAS-TAT chips when they are received, and our tests will pinpoint what modifications are needed on the first generation VAS-TAT chips. If the system works as designed, pixellated CdTe or CdZnTe detectors will be mounted and connected to the VAS-TAT system and measurements of complete detector systems will be started. If additional modifications are identified for the VAS-TAT chips, the fabrication of new VAS-TAT chips will be scheduled to be completed by the end of this year.

Presently, the modifications to the VAS-TAT system we anticipate include:
(1) Increase the output range of the VAS chips from 0.6 V to 3 V to match the input range of the ADC boards. (2) Improve the uniformity of the VAS output baselines of individual channels. (3) Improve the signal output quality of the first channels (#1 on each VAS chip). The rise time of the output from the first channel was too slow (~2 μs) to be useful on the first generation system, and should be reduced to ~200 ns on the new system. (4) Change to leading edge trigger on the first channel, instead of falling edge trigger on the first system. (5) Increase the gain of TAT chips, which converts electron drift times to voltage amplitudes, from ~100 mV/μs to ~300 mV/μs. (6) Shift the output baselines of the TAT chips from -1.8V to about 0V to improve the dynamic range of the chips.

4. **Objective:** Upgrading the first generation 3-dimensional position sensitive CdZnTe detectors in collaboration with Johns Hopkins University Applied Physics Laboratory

   Accomplishments: Two pairs (both of CdTe and CdZnTe) of 3-dimensional position sensitive detectors are currently being constructed. However, considering the challenge both in detector construction and upgrade of the readout electronics, we are also trying to upgrade the first generation 3-dimensional position sensitive CdZnTe detectors (built in 1998) in order to have a backup and an independent device. Although the first two 3-D CdZnTe gamma-ray spectrometers were demonstrated in 1998, there were several limitations on these devices. Each anode pixel was DC coupled to each independent preamplifier input of the VA1 chip. The leakage current collected at each anode pixel, although only a few nA in amplitude, saturated the preamplifiers at their normal working conditions. In order to accommodate the leakage current, the chips had to be operated at a different setting. As the result, the electronic noise was increased from ~3-4 keV to ~6-7 keV. To overcome the problem caused by the leakage current, we are adding a multi-channel resistor-capacitor array between the detector and the VA1 chip. Since the input pads of the VA1 chip have a very fine pitch, the wire-bonding modification requires specialized tools and skills. We are thus working with Johns Hopkins University Applied Physics Laboratory to upgrade the two detectors from DC coupling to AC coupling.

5. **Objective:** Design, construct and test data acquisition system for the Compton imagers**.**

   Accomplishments: Although each 3-dimension position sensitive CdZnTe detector worked well independently, an additional data acquisition system is needed to synchronize the operation of two independent 3-dimensional position sensitive detectors to form a Compton scattering imaging device. When both detectors record a coincident event, specialized control circuitry initiates the full readout of both detectors. A computer program written in C++ can read signals from all 244 channels on both detectors and perform data processing. This includes obtaining energy depositions and decoding the positions of each gamma-ray interaction for image reconstruction. If only one detector registers an event, the control circuitry resets both charge sensing amplifier chips so that the system is ready for the next event. This circuitry has been built and successfully tested. The control program has been written to perform a number of specialized tasks in software, such as to change energy thresholds on each detector, adjust the time delay between triggers of the two detectors for optimum coincidence measurement, and to synchronize the readout of two VA1 chips in parallel mode.

Conclusion: Parallel efforts have been carried out on detector construction. The first Compton-scattering gamma-ray imaging device using 3-D position sensitive semiconductor detectors should be assembled during the third year period of this project, and will be tested using gamma-ray sources of various shapes. The results will be summarized in the final report.

Publication:

Y.F. Du, Z. He, G.F. Knoll, D.K. Wehe, W. Li "Evaluation of a Compton Scattering Camera using 3-D Position Sensitive CdZnTe Detectors" Proceedings of SPIE, Denvor, Colorado, USA, July 18-23, 1999.

Y.F. Du, Z. He, G.F. Knoll, D.K. Wehe "Effects of Mechanical Alignment Errors on Compton Scattering Imaging" To appear in: IEEE Transactions on Nuclear Science, 2000.

Statement of Objectives
University of Michigan
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Overall Project Goal: To construct and test compact Compton imaging systems using 3-dimensional position-sensitive, room-temperature semiconductor gamma-ray spectrometers. Conventional Compton imaging devices are based on scintillation and/or HPGe detectors. Their imaging ability and compactness are limited by either the poor energy resolution of the scintillation detector or by poor position resolution. The world's first two 3-dimensional position sensitive semiconductor gamma ray detectors were built at University of Michigan in 1998 using CdZnTe and operated at room temperature. Energy resolution of ~1.7% FWHM and position resolutions of $\sim 1\times 1\times 0.5$ mm were achieved. With significantly better energy resolution than that of a scintillation detector and position resolution of ~1 mm, it is now possible to construct very compact Compton scattering gamma-ray imaging system based on these newly available detectors. Within the project period of 3 years, at least one prototype Compton imaging device will be built and tested.

Phase 3: Assemble and test the integrated Compton imaging system using radiation sources. Modify and refine the system both on the detector and imaging reconstruction algorithms based on the test results, and summarize the knowledge obtained in the project.

Phase 3 Deliverable: A final report at the end of phase 3 will describe the accomplishments as measured against the whole project objectives.

Phase 3 Funding - $147,921
Phase 3 Period - July 1, 2000 – June 30, 2001